INFLUENCE OF WET-BULB TEMPERATURE DURING CURING ON PROPERTIES OF SHADE-GROWN TOBACCO

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I. Introduction

Tobacco leaves undergo many complex changes as they cure from fresh green to a dried brown. Aside from a physical loss of water, there are changes in color, protein, carbohydrate, organic acids, and other constituents. The chemical reactions proceed until water becomes limiting (2). Thus rate of water loss affects the end result (1). During the time that water is not limiting, the speed of these reactions depends on temperature of the leaf tissues.

This bulletin reports a study of the influence of curing temperatures upon the physical properties and quality of shade-grown tobacco. It is assumed that leaf temperature in the early stage of the cure approximates the wet-bulb temperature.[1] Therefore, wet-bulb temperature was varied while maintaining the same drying conditions.

The progress of weight loss in leaves was followed, as also were the changes in leaf color and protein content during the curing process. After curing was completed, leaves were graded for color and uniformity of color, and these properties were related to temperatures extant during curing. Other physical properties were also evaluated at this time. Finally, leaves were fermented according to current methods and sorted into commercial grades. The relation of curing temperature to the commercial standards of quality was explored.

II. Experimental Methods

Field Methods

Shade-grown tobacco of the Connecticut 49 variety was grown in a small tent on the Experiment Station farm, with normal methods of fertilization and cultivation. Tobacco for curing constituted what is commercially called second and fifth primings, and was harvested at a stage of technical ripeness. Counting upward from the bottom of the plant the second priming includes leaf positions 4 through 6 and the

[1] The dry-bulb temperature is that recorded by an ordinary thermometer. The wet-bulb temperature is obtained by enclosing a thermometer bulb in wet wicking and blowing air past it. The cooling caused by evaporation of water causes the wet-bulb temperature to be lower than the dry-bulb temperature.

fifth priming positions 13 through 15. All other leaves on the plants were removed during the course of normal harvest.

Preparation of Samples

Each picking consisted of two leaves from successive stalk positions. Twenty samples of 20 leaves were obtained at each picking, according to a sampling scheme described by Vickery and Meiss (2). Each sample of 20 leaves was weighed soon after picking. The coefficient of variation of the fresh weight was 3.5 per cent for the second priming and 4.4 per cent for the fifth priming. Sixteen of the samples were sewn on laths and were designated to complete the curing process. The remaining four samples were divided into subsamples of six to eight leaves each and the fresh weights determined to the nearest gram on a triple-beam balance. These subsamples were removed at intervals during curing for the determination of dry matter and protein nitrogen. One sample of fresh leaves was analyzed for initial dry matter and protein nitrogen at the beginning of the curing process.

Curing Methods

A total of 20 laths of tobacco, including 4 laths which held the small subsamples, was equally divided between two air-conditioned curing cabinets. The design of the cabinets and the conditioning system, which supplies air of controlled temperature, humidity and velocity to the curing environment, have been described in a previous bulletin (1). The tobacco samples in the present experiment were hung in cabinets served by a different air-conditioner in order to cure the leaves at different atmospheric conditions.

In the low temperature cure the atmospheric conditions were maintained at 89° F. dry-bulb temperature, 61 per cent relative humidity, and 78° F. wet-bulb temperature. In the high temperature cure constant conditions were set at 98° F. dry-bulb temperature, 70 per cent relative humidity and 88° F. wet-bulb. Air velocity was approximately 25 feet per minute in both cases.

These atmospheric conditions were chosen to give a wide range of wet-bulb temperature while maintaining the same vapor pressure deficit or drying capacity of the air.[2]

It had been previously observed that leaves of shade-grown tobacco lose moisture at the same rate in atmospheres of equal vapor pressure deficit.

Evaporation was measured daily in each cabinet by means of spherical atmometers of the Livingston type. The daily average in the low temperature cure was 22 ml. compared to 28 ml. in the higher temperature cure.

[2]The vapor pressure deficit is the difference between the saturation vapor pressure and the actual vapor pressure of (unsaturated) air at the same temperature.

Three laths of 20 leaves each were weighed in each cabinet at the beginning of the curing and at 24-hour intervals until the process was completed. After 12 days in the cabinet, leaves were transferred to a standard curing barn.

III. Results

Loss of Weight

Loss of weight for each of the two primings in both the high and low temperature conditions is plotted against duration of curing in Figure 1. Within each priming very similar drying notes were obtained in the two different atmospheres. Data obtained in 1953 from the second priming, cured under virtually the same vapor pressure deficit, are also shown.

As one might expect, drying rate of the second priming in 1953 differs from that of the second priming in 1954. Rainfall was abundant in 1953 but deficient in 1954. The differences between drying rates of the second primings of 1953 and 1954 were smaller than the differences between second and fifth primings in 1954.

Leaves from the fifth priming lost 50 per cent of their weight in 2 days compared with 4 days for the same weight loss in second priming leaves. Thus, leaves from different positions on the plant dried at different rates, and one cannot accurately predict the drying rate of a given crop under known curing conditions of temperature and relative humidity.

Changes in Leaf Color during Curing

Forty individual leaves per treatment were graded into the color categories described in Bulletin 599 and Table 1, covering the range from green through yellow to brown. The daily progress of color changes during curing of the second priming and the changes in weight are given in Table 2.

Yellowing of the leaves proceeded at very similar rates in both cures during the first 2 days. Within this period the tobacco lost about 30 per cent of the original weight and on the whole attained a dominant color of yellow-green. A 10-degree spread in temperature did not result in any appreciable difference in the initial rate of yellowing. The rate of weight loss rather than temperature appears to be the dominant factor in causing loss of green pigment.

During the third and fourth days of curing color changes were a little more advanced in the 78° cure since at this time 7 leaves were classed as yellow-brown as compared to two leaves in the 88° cure.

The most notable difference in the rate of color change appeared on the sixth day when the leaves had lost about 70 per cent of their original weight. In the 88° wet-bulb cure there were 34 leaves on day 6 and 39 leaves on day 7 classed as 80 per cent or more brown. This contrasts with only 15 and 27 leaves in this class for the 78° cure. At the

Table 1. Color categories for describing changes in leaf color of shade-grown tobacco during curing

Category No.	Dominant color and description	Approximate ratios of green	yellow	brown
1	Green. Deep green color of the harvested leaf.	10	0	0
2	Light Green. Decidedly green but showing a slight yellow cast.	9	1	0
3	Yellowish-Green. Much green but small amount of yellow present.	8 - 7	2 - 3	0
4	Yellow-Green. More green than yellow. Slight amount of brown if any.	6 - 5	4	0 - 1
5	Yellow. More yellow than green. Small amount of brown if any.	4 - 3	6 - 5	0 - 2
6	Brownish - Green - Yellow. About equal yellow and green. Small amount of brown.	4 - 3	4	2 - 3
7	Brown-Yellow. Yellow in excess of brown. Some green persisting.	2	5 - 6	3 - 2
8	Yellow-Brown. About equal brown and yellow. Small amount of green.	2 - 1	4 - 3	4 - 5
9	Yellowish - Brown. Considerable brown. Some yellow and trace to slight amount of green	1	3 - 2	6 - 8
10	Brown. Virtually all brown. Trace of yellow, green or both, if any.	0 - 1	1 - 0	9 - 10

higher temperature all 40 leaves were cured in 10 days while 12 days were required to reach this stage at the low temperature.

Leaves in the fifth priming were similarly affected by temperature as shown by the data in Table 3. During the first 2 days of curing yellowing took place as rapidly at 78° as at 88° wet-bulb temperature. The number of green and yellow-green leaves were approximately the same in both cures showing that chlorophyll breakdown is linked to the rate of moisture loss during the initial stages of curing.

The formation of brown pigments started on the third day when leaves in both cures had lost 60 per cent of their original weight. Again browning was more rapid in the higher temperature cure. As the curing progressed toward conclusion, the formation of brown pigments and the appearance of cured leaves continued to be accelerated. Thus, results obtained in the late priming are in agreement with those from the early priming.

As the leaves dry to 50 per cent of their original weight the rate of moisture loss has a larger influence on color change than does temperature. The point at which browning begins may well depend on the degree of moisture lost but once browning has begun temperature strongly influences its rate of progression. This phenomenon is probably an effect on the rate of oxidation reactions which are known to function in the formation of brown pigments characteristic of wrapper tobacco.

Table 2. Progress of visible color changes in a 40-leaf sample of shade-grown tobacco as influenced by wet-bulb temperature during curing. Connecticut 49 variety, crop of 1954, second priming

Days of Curing	Wet-bulb temp.	Per cent orig. wt. retained	Number of leaves in color category: Green 1	Green 2	Yellow-green 3	Yellow-green 4	Yellow 5	Yellow 6	Yellow-brown 7	Yellow-brown 8	Brown 9	Brown 10
0	Low*	100	40	—	—	—	—	—	—	—	—	—
	High†	100	40	—	—	—	—	—	—	—	—	—
2	Low	68	—	15	22	3	—	—	—	—	—	—
	High	69	—	17	21	2	—	—	—	—	—	—
4	Low	50	—	—	—	6	24	3	7	—	—	—
	High	50	—	—	—	5	25	8	1	—	1	—
6	Low	31	—	—	—	—	6	1	8	10	12	3
	High	32	—	—	—	—	—	2	—	4	32	2
8	Low	20	—	—	—	—	—	—	—	—	15	19
	High	20	—	—	—	—	—	—	4	2	8	32
10	Low	14	—	—	—	—	—	—	—	—	6	34
	High	15	—	—	—	—	—	—	—	—	—	40
12	Low	12	—	—	—	—	—	—	—	—	—	40
	High	13	—	—	—	—	—	—	—	—	—	40

*Atmospheric conditions were 78°F wet-bulb, 89°F dry-bulb, 61 per cent relative humidity.
†Atmospheric conditions were 88°F wet-bulb, 98°F dry-bulb, 77 per cent relative humidity.

Table 3. Progress of visible color changes in a 40-leaf sample of shade-grown tobacco as influenced by wet-bulb temperature during curing. Connecticut 49 variety, crop of 1954, fifth priming

Days of curing	Wet-bulb temp.*	Per cent orig. wt. retained	Number of leaves in color category: Green 1	2	Yellow-green 3	4	Yellow 5	6	Yellow-brown 7	8	Brown 9	10
0	Low	100	40	—	—	—	—	—	—	—	—	—
	High	100	40	—	—	—	—	—	—	—	—	—
1	Low	69	11	28	1	—	—	—	—	—	—	—
	High	66	8	31	1	—	—	—	—	—	—	—
2	Low	52	—	—	11	22	7	—	—	—	—	—
	High	50	—	—	7	29	4	—	—	—	—	—
3	Low	41	—	—	—	4	21	3	6	5	1	—
	High	38	—	—	—	—	5	4	10	13	7	1
4	Low	32	—	—	—	—	2	—	8	14	15	1
	High	30	—	—	—	—	—	—	2	11	19	8
5	Low	27	—	—	—	—	—	—	—	5	26	9
	High	26	—	—	—	—	—	—	—	—	14	26
6	Low	23	—	—	—	—	—	—	—	—	18	22
	High	23	—	—	—	—	—	—	—	—	5	35
7	Low	21	—	—	—	—	—	—	—	—	7	33
	High	22	—	—	—	—	—	—	—	—	3	37
8	Low	20	—	—	—	—	—	—	—	—	2	38
	High	20	—	—	—	—	—	—	—	—	—	40

*See footnote, Table 2.

Dry Matter and Protein Nitrogen

Small subsamples of the second priming were removed from the chambers at intervals of 0, 1. 2, 4, and 12 days of curing. In the last sample curing of the leaf web was complete although the midrib was not entirely dried. Subsamples in the fifth priming were taken at 0, 1, 2, 4, 6, and 8 days of curing. This accelerated schedule was necessitated by more rapid curing than in the second priming. Upon removal from the curing cabinet each subsample of six or eight leaves was weighed and the web and midrib separated. Both leaf parts were then placed in a forced air drying oven and dried 80°F for 18 hours or until the midribs were brittle. After determining total dry matter the midribs were discarded and the web stored in tight-stoppered glass bottles for later analysis of protein nitrogen.

Dry Matter

Changes in dry matter for the second and fifth priming are shown in the upper curves of Figures 2 and 3 respectively. Second priming

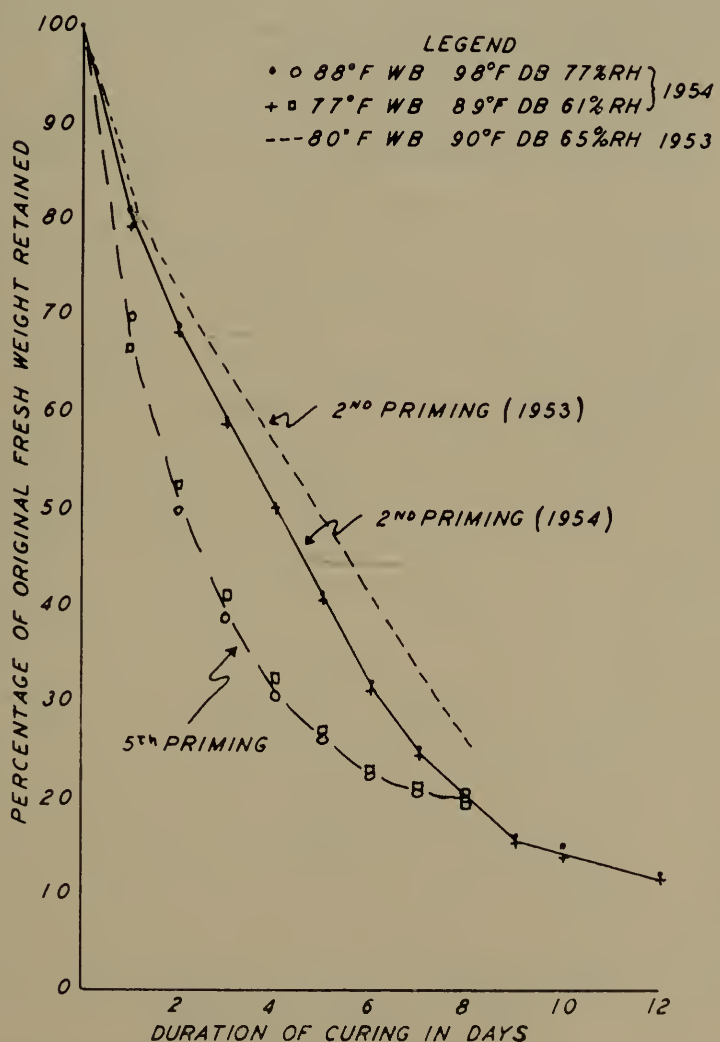

Figure 1. Weight loss for three primings of shade-grown tobacco leaves cured under similar drying conditions.

leaves cured at the higher temperature retained less of the original dry matter content than those cured at the lower temperature. The higher rate of dry matter loss during the first 4 days apparently accounted for this difference.

Fifth priming leaves behaved somewhat differently. Initial loss during the first 4 days was again more rapid at the higher temperature. However in the fully cured leaf there was greater retention of dry matter by leaves cured at the higher temperature. Loss of dry matter stopped after the fourth day at high temperature but did not do so at the low temperature. Leaves of this priming dried much more rapidly than those of the second priming so that water became a limiting factor sooner in the cure. Total percent of dry matter at both temperatures was higher for the fifth priming, confirming numerous observations that upper priming leaves are heavier bodied.

Change in Protein Nitrogen

The finely ground leaf powder was analyzed for protein nitrogen by the method of Vickery and Meiss (2) and results are expressed as grams of protein N per kilogram of fresh weight.

During curing, protein disappeared more rapidly and completely at the lower wet-bulb temperature in both primings (Figures 2 and 3).

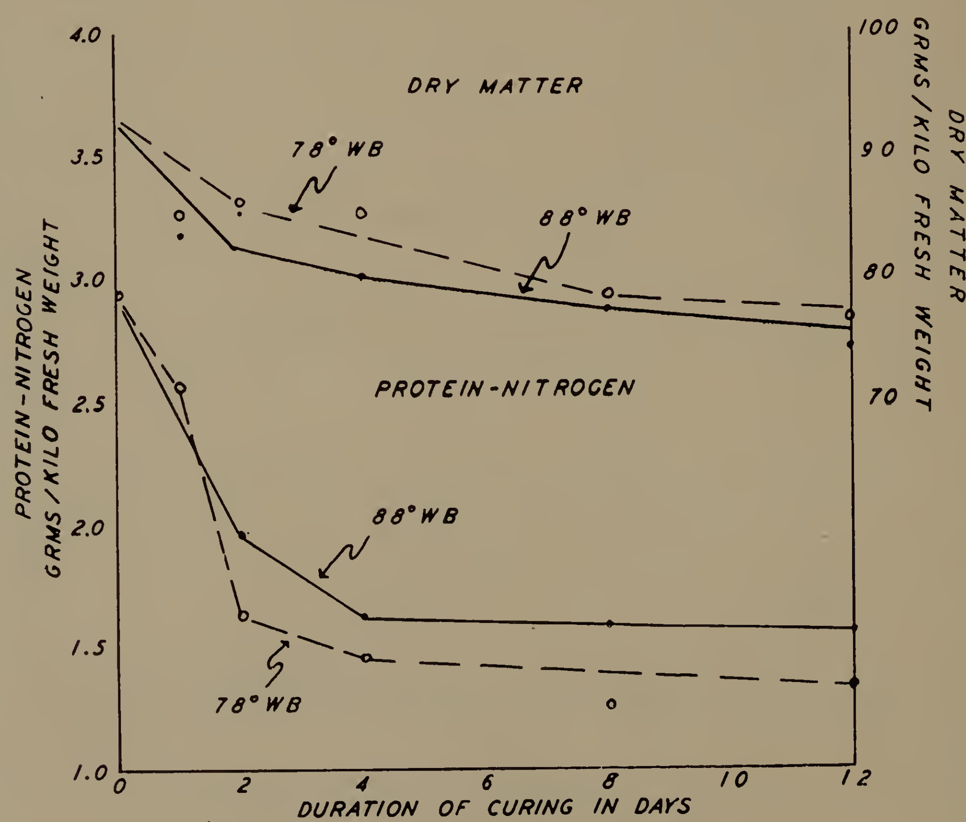

Figure 2. Effect of wet-bulb temperature on dry matter and protein-nitrogen content of second priming shade-grown tobacco. Connecticut 49 variety, 1954.

In both primings, protein breakdown ceased after the fourth day at 88° but continued slowly at 78°. Although the rate of weight loss was similar within primings the pattern of protein hydrolysis was different.

The lamina of fresh leaves picked earlier had a protein N content of 2.93 grams per kilogram of fresh weight as compared with 3.95 in the late picking. The cured leaves of the late picking also showed a higher protein nitrogen content under similar curing conditions. This difference in protein content is an agreement with the stronger taste and aroma noted in cigars wrapped with the upper leaves of shade tobacco.

The rate of protein hydrolysis slowed down or became negligible in the second priming when the amount of weight had diminished to near 50 per cent of the original. The leaves at this point were in the yellow stage of color change with small amounts of green and brown pigments present. However, in the fifth priming the same behavior of protein hydrolysis did not occur until the tobacco had lost all but approximately 30 per cent of the original weight. The leaves of this priming had passed the yellow stage of color and had reached a mild brown or yellow brown color. For both primings the point of time in question was the fourth day of curing.

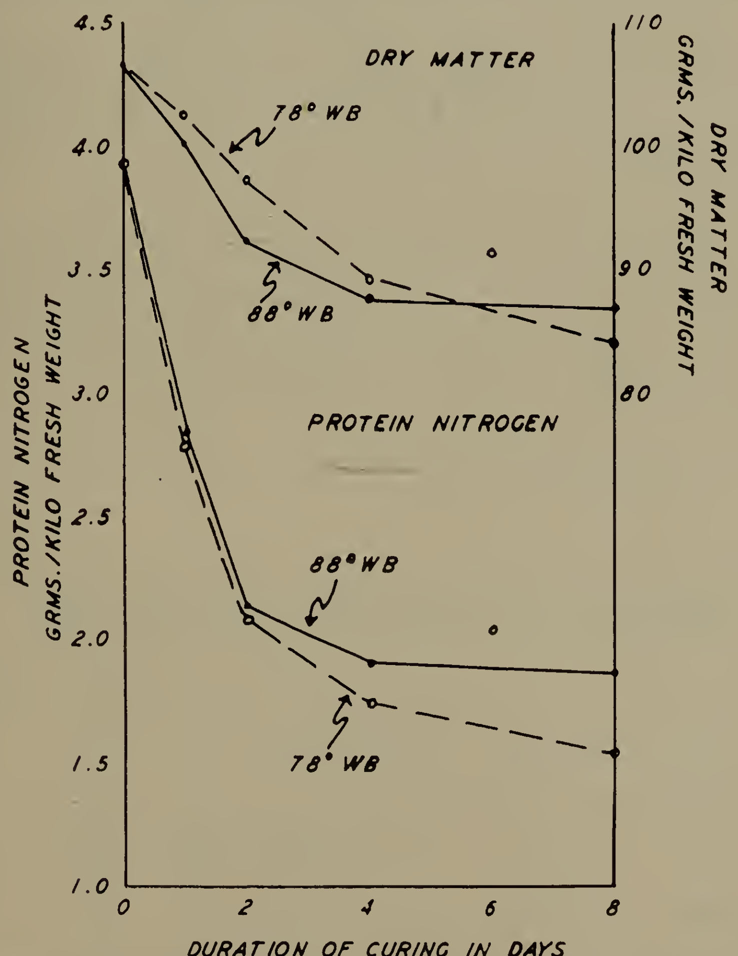

Figure 3. Effect of wet-bulb temperature on dry matter and protein-nitrogen content of fifth priming shade-grown tobacco. Connecticut 49 variety, 1954.

Table 4. Degrees of muddiness (blackish pigment) in cured unfermented leaves of shade-grown tobacco, with an arbitrary scale of rating

Degree	Description	Rating
Clean	Less than 5 per cent of leaf surface showing a very dark blackish or greyish black pigment.	10
Slight	From 5 to 10 per cent of leaf surface affected.	8
Moderate	From 10 to 25 per cent of leaf surface affected. Leaf colors dull.	5
Muddy	From 25 to 50 per cent of leaf surface affected. Colors very dull and dark.	3
Very muddy	Over 50 per cent of leaf surface affected. Very dark, blackish colors.	1

IV. Physical Properties of the Cured Leaf

Muddiness

Five grades of muddiness[3] were established and a rating was assigned each grade (Table 4). The 160 leaves in each treatment were graded as to muddiness, and the number in each grade was expressed as a percentage of the total sample. From these data a muddiness index was computed by multiplying the rating by the percentage of leaves in that grade, summing these products for five grades, and dividing by 100 (Table 5).

The tobacco cured at the lower temperature showed much less muddiness than that cured at 88°. In the second priming, about 30 per cent of the leaves cured at 78° were graded as muddy or very muddy, whereas about 75 per cent of the leaves cured at 88° showed a great amount of black pigment. Growers of shade tobacco have long known that muddiness is more common in the lower leaves.

[3]Muddiness is the occurrence of dark grey to black pigment in the cured leaf, localized or general in distribution and giving the leaf a dirty appearance.

Table 5. Distribution of muddiness in cured unfermented tobacco leaves as influenced by wet-bulb temperature during curing

Leaf position	Wet-bulb temp.	Drying rate	Degrees of muddiness and rating: Clean 10	Slight 8	Moderate 5	Muddy 3	Very muddy 1	Muddiness index
			Per cent of total sample					
4 - 6	Low	12.5	4	28	38	24	6	5.3
	High	12.6	0	6	18	36	40	2.9
13 - 15	Low	17.0	37	46	14	3	0	8.2
	High	17.4	27	40	23	10	0	7.4

The strongly black tobacco in the second priming at 88° suggest the effect of temperature on oxidative changes during curing. The rate of brown pigment formation during curing was higher at the higher temperature (Table 2). Under the influence of the higher temperature, the oxidative reactions were apparently intensified and blackish pigments resulted. While nutrition and other factors during the growth of the plant may govern potential muddiness, curing temperatures obviously can be a decisive factor in the development of muddiness.

In the fifth priming the number of muddy leaves was much lower, but there were three times as many muddy leaves in the cure at 88° (Table 5).

Uniformity of Color

Seven grades were established to cover the range of uniformity of color and a rating was assigned to each grade (Table 6). Leaves were then classed according to these grades and a uniformity index was com-

Table 6. Degrees of color uniformity in cured leaves of shade-grown tobacco with an arbitrary scale of rating

Degree	*Description*	Rating
Very good	Approximately 95 to 100 per cent of surface one color. Very small spots or areas, if any, of a different color.	10
Good	Approximately 85 to 95 per cent of surface one color. Small spots or areas of a different color.	9
Fair	Approximately 75 to 85 per cent of surface one color. Sizeable spots or areas of a different color.	7
Non-uniform	Approximately 55 to 75 per cent of surface one color. Large spots or areas of a secondary color. Small amounts (up to 10 per cent) of a third color allowed.	5
Mixed Colors	Approximately 50:50 distribution of two different colors or a 50:25:25 distribution of three colors.	4
Variable colors	Three distinct colors about evenly distributed. No single color dominant.	2
Mottled colors	Intermingling spots or areas of several different colors giving the leaf a dappled appearance. No one or two colors dominant.	1

Table 7. Uniformity of color of cured unfermented leaves of shade-grown tobacco as influenced by wet-bulb temperature during curing. Connecticut 49 variety, crop of 1954

Leaf position	Wet-bulb temp.*	Drying rate	Degree of color uniformity and rating: Very Good 10	Good 9	Fair 7	Non-uniform 5	Mixed colors 4	Variable colors 2	Mottled colors 1	Uniformity Index
			Per cent of total sample							
4 - 6	Low	12.5	3	33	43	21	0	0	0	7.3
	High	12.6	1	29	51	19	0	0	0	7.2
13 - 15	Low	17.0	16	35	30	15	4	0	0	7.8
	High	17.4	26	46	24	3	1	0	0	8.6

*See footnote, Table 2.

puted in a manner analogus to the muddiness index. This grading was for uniformity of color and not for desirability of color.

In the second priming no appreciable differences in uniformity of color were found between the tobaccos cured at 78° and 88° wet-bulb temperature (Table 7). The data show a slightly higher percentage of leaves with very good uniformity in the 78° cure but also a greater amount of tobacco being graded as non-uniform. Neither cure resulted in leaves having highly variable or mottled color. The colors encountered in individual leaves blended well together. This was because the dominant shades of dark brown in the 78° cure and very dark brown in the 88° cure were blended with slightly lighter shades of brown in varying amounts. There were no leaves in either cure that exhibited areas or spots of red, green or yellow. Leaf tips were generally uniform in color with the butt end.

Curing the leaves of fifth priming at 88° wet-bulb temperature resulted in somewhat better color uniformity than at 78° (Table 7). At the higher temperature 71 per cent of the leaves showed good to very good uniformity of color as compared to 50 per cent at the cooler temperature. About four times as much tobacco was found to have non-uniform or mixed colors in the 78° cure and as a result the value of the uniformity index was about one unit lower.

The tobacco in the cooler cure showed some spotting with small (dime-size) greenish areas and occasionally reddish or yellowish areas. About half of the leaves were characterized by very tiny spots of a dull grey-green color in the butt half. In most instances these tiny spots were few in number, while in a few leaves they were coalesced into a single area about one inch in diameter. This "freckling" was not found in any of the leaves cured at 88°. At the higher temperature there was only slight occurrence of green, yellow, or red areas and the dominant brown and greenish brown shades blended harmoniously in the great majority of leaves.

Color

Fourteen grades were established to describe the predominant color of leaves (Table 8). These colors ranged from green to reddish brown. Leaves were classed according to these grades (Table 9). The color grades do not correspond precisely with the ones previously used (Bul. 599) but differences are indicated in Table 8.

The tobacco of second priming cured at 88° was generally of very dark color (Table 9). Almost all of the leaves graded as dark to very dark greenish brown (grade 8) and very dark brown or blackish (grade 11). Few leaves were light enough in color to be graded moderately dark brown (grade 10). No leaves showed either a definite or fairly strong green cast or red cast. The absence of green color in the leaves did not appear to be due to a masking by the predominant shades of very dark brown or black. The destruction of chlorophyll was observed

Table 8. A schedule of color classes or grades for cured, unfermented leaves of shade-grown tobacco

Color class No.	Description	Munsell color numbers* Hue	Chroma value
1	Dark to very dark green or brownish green. Green highly dominant.	10Y or 7.5Y	3/2, 3/3, 3/3.5, 3/4, 3.5/4, 4/3
2	Moderately dark green or brownish green. Green dominant over brown.	10Y or 7.5Y	4/4, 4/5, 4.5/4, 4.5/4.5, 5/3, 5/4
3	Light to medium green or yellowish green. Occasional light brown cast.	10Y or 7.5Y	4/6, 4.5/6, 5/4.5, 5/5, 5/6
4	Dark to very dark green brown. Dark olive. About equal green and brown.	5Y	3/2, 3/3, 3/3.5 3/4, 3.5/4, 4/3
5	Moderately dark green brown. Medium olive. Approximately equal green and brown.	5Y	4/3.5, 4/4, 4/5, 4.5/4, 5/3
6	Light to medium green brown. Light olive. Approximately equal green and brown.	5Y	4/6, 4.5/6, 5/4, 5/4.5, 5/5, 5/6
7	Light to medium brown or greenish brown. Occasionally yellowish brown. Noticeable greenish cast.	2.5Y or 4Y	4/6, 4.5/6, 5/4, 5/4.5, 5/5, 5/6
8	Moderately dark to dark brown or greenish brown. Brown dominant over green. Noticeable green cast.	1Y 2.5Y 4Y	3/4, 3.5/4, 4/3, 4/3.5, 4/4, 4/5
9	Light to medium brown. Neutral or slight reddish cast.	10YR	4/6, 4.5/4, 4.5/6, 5/4, 5/5, 5/6
10	Moderately dark to dark brown. Neutral or slight reddish cast.	10YR	3/4, 3/5, 3.5/4, 4/3, 4/4, 4/5, 5/3
11	Very dark brown or blackish. Mostly a neutral cast.	2.5Y 10YR	3/2, 3/3, 3/3.5, 3.5/3
12	Light to medium reddish brown or red brown. Moderate to strong red cast.	7.5YR 5YR	4/5, 4/6, 4.5/6, 5/4, 5/5, 5/6
13	Moderately dark to dark reddish brown or red brown. Medium to strong red cast.	7.5YR 5YR	3/4, 3.5/4, 4/3, 4/4, 5/3
14	Very dark reddish brown or red brown. Magenta or somewhat purplish cast.	7.5YR 5YR	3/2, 3/3, 3/3.5, 3.5/3

*Munsell color standards. Munsell Color Company, Baltimore, Md.

during curing to have been accelerated by the high temperatures (98° dry-bulb, 88° wet-bulb) and reached a high degree of completion. In addition the drying rate was slow enough to prevent moisture from becoming a limiting factor early in the cure.

Curing the second priming at 88° resulted in very dull colors and rendered the tobacco virtually useless for cigar wrapper.

The general color of the tobacco cured at 78° wet-bulb temperature was quite different (Table 9). This tobacco had a mild red cast and the shades of brown were definitely lighter. At 78° no blackish colors resulted, although about 14 per cent of the leaves were a very dark red brown. The absence of any more than a slight green cast in both cures suggests that a rate of drying of 12.5 per cent is slow enough to permit extensive destruction of chlorophyll.

The tobacco cured at the lower temperature graded largely as moderately dark to dark brown or greenish brown (grades 10 and 8, respectively) with 20 per cent of the sample falling into the dark red browns (see Table 5). The colors on the whole were too dark for high quality wrapper tobacco.

Curing leaves of fifth priming at different wet-bulb temperatures did not result in striking differences in leaf color. The great bulk of tobacco in both cures was graded into color grades 8, 10, and 11. At 88° a somewhat greater quantity of moderately dark to dark greenish brown tobacco was produced (grade No. 8) while the cooler temperature favored a little more tobacco of a very dark brown color (grade No. 11).

The dominant color of the tobacco cured at 88° was a deep, dark brown or greenish brown. There were no light colored leaves or leaves with a definite reddish cast. The darkest colored leaves (grade No. 11) showed a small amount of very dark pigment but the colors did not appear blackish in contrast to the definite blackness which characterized the second priming leaves cured at 88°. This would suggest that the precursor substances for black pigment are less concentrated in the later maturing leaves. Other factors such as enzymes in black pigment formation may also be of lesser activity.

The greenish cast in the tobacco cured at 88° was not especially strong despite a fast rate of drying of 17.4 per cent (average daily loss during first 96 hours of curing). However, this tobacco showed a noticeably stronger greenish cast than that cured at 78°. Four per cent of the sample was a moderately dark green brown color as compared to one in the cooler cure.

The tobacco cured at 78° was principally moderately dark to dark brown in color. A slight greenish cast prevailed in approximately half of the leaves. Reddish shades of color were virtually absent and there was no blackish tobacco. A small amount of tobacco was found to have fairly light brown colors. The leaf colors in the 78° cure tended to be brighter and more acceptable than those resulting from the higher wet-bulb temperature. However, in both cures the colors were too dark for the tobacco to be judged as having a high degree of quality.

Table 9. Color grading and color indexes of cured, unfermented leaves of shade-grown tobacco as influenced by wet-bulb temperature during curing. Connecticut 49 variety, crop of 1954

			Percentage of sample‡ in color class number										
	Wet-bulb	Drying	Green-brown				Brown				Red-brown		Color
Priming	temp.*	Rate†	5	6	7	8	9	10	11	12	13	14	index
Second	Low	12.5	—	—	—	38	—	42	—	—	6	14	10.0
	High	12.6	—	—	—	74	—	3	23	—	—	—	8.7
Fifth	Low	17.0	—	—	—	43	2	22	32	—	1	—	9.5
	High	17.4	4	—	—	49	—	21	26	—	—	—	9.1

*See footnote, Table 2.

†Drying rate is expressed as the average percentage of original fresh weight lost daily during the first 96 hours of curing.

‡Total sample contains 160 leaves.

The results of curing studies to date in which drying rates and wet-bulb temperatures have been separately varied suggest the following conclusion. In regards to the color of the cured leaf, variations in drying rate appear to have a greater influence in late primings than in early primings (1953 studies). On the other hand, variation in wet-bulb temperature seems to have a greater influence than drying rate in the case of the early primings. It is not possible with data obtained thus far to explain why these observations seem to be true.

Miscellaneous Physical Properties

One notable effect of wet-bulb temperature during curing was in connection with the occurrence of stain or bleeding stem in the second priming. About 10 per cent of the leaves cured at 88° showed slight to moderate staining. Moderate staining is herein defined as a strip of stained tissue 2 to 5 inches long and up to three-fourth inches wide along one or both sides of the midrib. The same priming cured at 78° wet-bulb was found to have no leaves showing stain. Thus it appears that the condition of staining is favored by combined high temperature and humidity during curing. In small curing barn studies in 1953 it was observed that conditions of 102° dry-bulb temperature and 65 per cent relative humidity caused severe damage to shade tobacco by staining or bleeding stem.

In the present experiment no staining occurred in leaves of fifth priming at either 78° or 88° wet-bulb temperature.

No appreciable differences in leaf texture or feel could be attributed to the wet-bulb temperature maintained during curing. The second priming leaves had a rough, sandy feel whether cured at 78° or 88°. The cured leaves of the fifth priming had a soft, smooth texture in both cures.

Table 10. Distribution of fermented leaves of shade-grown tobacco among commercial grades as influenced by wet-bulb temperature during curing. Each sample contains 160 leaves. Connecticut 49 variety, crop of 1954

			Percentage of sample in commercial grades						
Leaf position	Wet-bulb temp.*	Drying rate	YL	LV	LV2	V	V2	KV	Grade Index†
4 - 6	Low	12.5	1	3	16	25	24	31	5.7
	High	12.6	—	—	—	10	13	77	2.0
13 - 15	Low	17.0	10	10	28	39	12	1	9.8
	High	17.4	—	11	24	33	24	8	8.4

*See footnote, Table 2.

†The grade index is calculated from the following values assigned to each commercial grade.

Grade	*Value*	*Grade*	*Value*
YL	10	V	8
LV	17	V2	3
LV2	13	KV	1

The cured leaves were sorted for body or thickness, in an entirely subjective manner. It was found that the leaves of the early priming tended on the whole to be thinner at the higher wet-bulb temperature of 88°. About 67 per cent of the leaves were judged to be thin bodied in the 78° cure as compared to 85 per cent in the 88° cure. The balance of the leaves in each cure were graded as medium bodied. On the other hand, the lower wet-bulb temperature favored a slightly thinner leaf in the fifth priming. Fifty per cent of the leaves were very thin in body as compared to 40 per cent in the 88° cure.

These grading results for leaf thickness tend to agree with the findings on dry matter analyses of the cured leaf. The dry matter content of the second priming was slightly lower in the leaves cured at 88° but higher in the cured leaf of fifth priming.

No damage to the leaves from pole rot was found in either priming or at either wet-bulb temperature. The high dry-bulb temperature along with adequate air movement and ventilation around the leaves was effective in preventing pole rot at a comparatively high relative humidity of 70 per cent. It would be dangerous, however, to maintain a similar humidity in shades of shade-grown tobacco because of the tight packing of the leaves and inadequacy of air movement in most parts of the shed.

Commercial Grading

The results of the commercial grading of the two primings are given in Table 10. The data are in terms of percentage of total sample and show the comparative effects of curing at different wet-bulb temperature and similar drying rates (within primings). The grade indexes were computed from the grade values given in the footnote. Descriptions of the various commercial grades are given elsewhere (Conn. Agr. Exp. Sta. Bul. 569, and Storrs Agr. Exp. Sta. Bul. 180).

The commercial quality of the second priming was exceedingly poor where the curing was conducted at 88° wet-bulb temperature. Ninety per cent of the leaf graded into the very poor quality grades of V2 and KV. These grades represent leaves having very dark, blackish color, and which are worthless for cigar wrappers. Thus the very dark colors prevailing in the cured leaves were indicative of very poor commercial quality. It may be concluded that curing early primings under conditions of high wet-bulb temperature and humidity is highly inadvisable.

The tobacco cured at 78° was of poor commercial quality, although the grade index was three times higher than that of tobacco cured at 88°. The cooler temperature resulted in 55 per cent V2 and KV tobacco, which is suggestive of the overall poor quality. However, about 20 per cent of this tobacco graded into the best quality dark grades, LV and LV2. as compared to none in the tobacco cured at 88°. Neither cure yielded any tobacco in the high quality grades of light-colored leaf, LL and LC. The lightest colored cured leaves (color grade 10) in this cure darkened somewhat during fermentation but all graded into the LV and LV2 grades.

It seems from the grading data of both cures that the method of curing was not entirely responsible for the poor quality. While raising the wet-bulb temperature 10 degrees resulted in a marked increase of V2 and KV tobacco, the occurrence of considerable dark tobacco in the cooler cure suggest other causes. Weather conditions, mineral nutrition, and other growing factors in 1954 very likely played a role, yielding leaves of potentially poor quality, and the manner of curing did not materially improve the situation.

Curing the fifth priming at 78° and 88° wet-bulb temperatures resulted in very little difference in net leaf quality. Grade index values were 9.8 and 8.44, respectively, indicating a definite improvement in quality over second priming cured under similar conditions.

The principle difference in grading occurred in the poor quality grades of the dark-colored leaves. Curing the leaves at 88° resulted in 8 per cent KV and 24 per cent V2 tobacco as compared to 1 and 12 per cent, respectively in that cured at 78°. The percentages in the other dark grades, LV, LV2 and V were similar. Thus curing the fifth priming at the lower wet-bulb temperature resulted in a small improvement of quality and gave a more favorable distribution of leaves in the dark commercial grades.

No light color leaf occurred in the 88° cure. On the other hand, 10 per cent of the tobacco graded as YL in the cooler cure indicating the latter favored somewhat lighter colors.

It will be recalled that the color of the cured leaf of fifth priming was not appreciably affected by a difference of 10 degrees in wet-bulb temperature. The slight differences in commercial grading noted above are in agreement with this earlier finding. Previous drying rate studies as well as the present study have shown that commercial leaf quality can be predicted to a considerable degree from the color grading of the cured leaf. A high yield of dark colored or strongly red or green colored leaves in the curing will be indicative of low quality after normal fermentation. On the other hand, if the curing produces a high yield of light colored leaves (color grades 6, 7 and 9), there will be a high percentage of leaves in the better grades of shade tobacco after fermentation. Thus the importance of proper curing to the attainment of good quality wrapper tobacco has been demonstrated.

V. Summary

Mature leaves of Connecticut 49 variety of shade-grown tobacco were cured in atmospheres of controlled dry- and wet-bulb temperatures, relative humidity and air velocity. The curing of each of the two primings (second and fifth) was operated to obtain two different rates of chemical changes by variation of the wet-bulb temperature while maintaining similar drying rates. Loss of total weight, and visible color changes, were followed during the course of the curing. Samples of leaves were removed periodically during curing to follow changes in dry matter and protein nitrogen. The cured leaves were graded or

examined for each of several physical properties which are associated with quality in cigar wrapper tobacco. After normal fermentation the tobacco was sorted into commercial grades and the overall quality assessed.

Virtually equal drying rates were attained within each cure by maintaining equal vapor pressure deficits in the different curing atmospheres. Leaves on the plant stalk appear to lose weight faster than lower leaves cured under the same atmospheric conditions.

At equal rates of drying the yellowing process proceeded at similar rates, despite a wet-bulb temperature difference in the two curing atmospheres of 10°. However, the formation of the brown pigments was noticeably accelerated at the higher wet-bulb temperature. Thus the breakdown of chlorophyll or the yellowing process appears dependent upon rate of moisture loss, while the browning of the leaves, once begun, is strongly influenced by temperature.

The higher wet-bulb temperature resulted in a faster rate of dry matter loss during the curing of both primings. The rate of protein breakdown, however, was more rapid at 78° wet-bulb temperature than at 88°. The lamina of fresh leaves picked earlier had a protein-nitrogen content of 2.93 grams per kilo of fresh weight as compared to 3.95 grams in the later picking.

The color of the cured leaf was greatly influenced by wet-bulb temperature in the case of the early picking. The higher wet-bulb temperature resulted in a much greater amount of very dark brown or blackish colored leaves. Differences in wet-bulb temperature did not result in appreciable color differences in the cured leaves of the late priming. This and an earlier study (1) have suggested that cured leaf color is more influenced by temperature than by drying rate in the early pickings of shade-grown tobacco. In the late pickings the reverse seems to be true.

Uniformity of color was not influenced appreciably by different wet-bulb temperatures during curing. Muddiness (black pigment) was greatly increased by the higher wet-bulb temperature in the early picking but only slightly so in the late priming.

Commercial grading showed that a combination of high wet-bulb temperature and relative humidity is very deleterious for the curing of early primings of shade tobacco. Mostly black leaf of very poor quality resulted. Wet-bulb temperature had only slight effect on the quality of the late priming with somewhat better quality favored by the lower wet-bulb temperature.

Literature Cited

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